Results from Persistence Mapping of Solar Imager Data

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ABSTRACT

Persistence Mapping is a simple image processing technique that is useful for the visualization and depiction of gradually evolving or intermittent structures. Persistence Mapping allows the user to isolate extreme values in a data set, and is particularly useful for the problem of capturing phenomena that are evolving in both space and time.

While integration or "time lapse" imaging uses the full sample (of size N), Persistence Mapping rejects (N-1)/N of the data set and identifies the most relevant 1/N values using the following rule: if a pixel reaches an extreme value, it retains that value until that value is exceeded. The simplest examples isolate minima and maxima, and the technique has been used to extract the dynamics in long-term evolution of comet tails, erupting material, CMEs, and EUV dimming regions.

METHODOLOGY

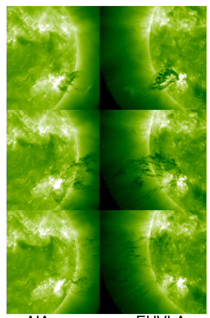
For a data set consisting of N images with intensity values I(x,y,t), the Persistence Map P_n is a function of several arguments, namely intensity, location and time:

$P_n(x,y,tn)=Q(I(x,y,t \le t_n))$

Common "Q" examples:
Minima   Maxima
Span/range   Time map

Give it a try!

```
> per=img
> for i=1,n-1 do per(*,*,i)=img(*,*,i)<per(*,*,i-1)
```



AIA   EUVI-A
7 June 2011 5:40 – 7:40 UT

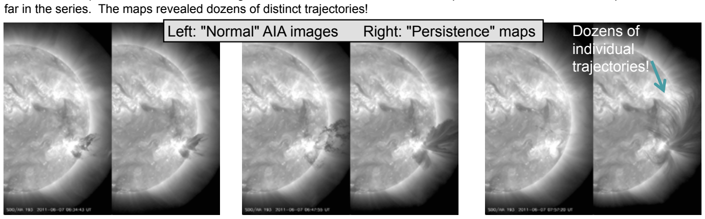
Example problem: Too much information

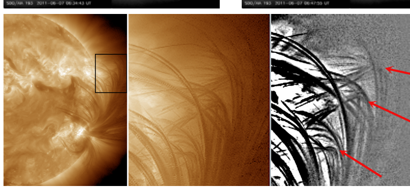
Gilbert et al., 2013: The challenge was to map the 3-D trajectories of falling blobs of dark prominence material following a solar eruption on 7 June 2011. The falling material was observed to produce energetic brightenings as they fell back and impacted the Sun. An accurate estimation of the velocity was important for the determination of the kinetic energy of the impacting material.

The trajectories were not ballistic, as they were modified by local magnetic field. The 3-D motion was quite complex, with acceleration, deceleration, and tracks of the blobs crossing each other multiple times.

Right figure: Observations were available from EUV images at two vantage points: (STEREO-A EUVI and SDO AIA). The challenge was to determine which pieces of material observed from one vantage point corresponded to material viewed from another vantage point.

Persistence maps were made from the images. Each consecutive frame in the map retains the lowest value the pixel has reached thus far in the series. The maps revealed dozens of distinct trajectories!





Left figure: (From Thompson & Young, 2016) A closeup view the trajectories in the above Persistence Map. The box in the left panel shows the location of the closeup views in the second panel. The third panel is an enhanced version of the second panel. The red arrows indicate sharp bends in the trajectory of some pieces of prominence. The assumption that an individual trajectory would be ballistic or even lie in a single plane ***is invalid.***

The pieces of material could exhibit drastic acceleration and sharp "knees" in trajectories were not uncommon. [Reference: Uritsky et al., 2016, in preparation]

Example problem: Evolving post-eruption dimmings

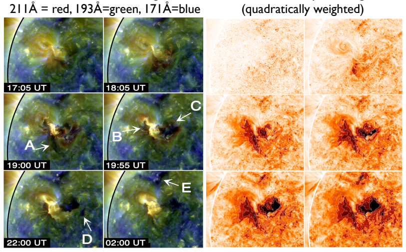
"Coronal dimmings," i.e. dark regions on the Sun that accompany an eruption, have been shown to be an effective indicator of evacuated material in the low corona. However, dimming regions can evolve over many hours, and one part of the dimming can completely "refill" before another part appears. Additionally, bright flare loops can obscure part of the dimmings.

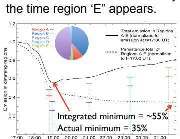
Persistence maps were constructed for the regions using the minimum criterion. Persistence eliminates the flaring region completely, solving the obscuration problem. The full extent of the dimming regions are identified over the course of 8 hours.

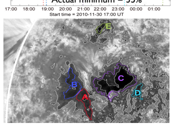
Images at right: SDO AIA combined wavelength images for the dimming/flare/CME event on 2010 November 30,. Regions A - E all exhibited dimming at some point during the event, but the much of the early dimming has disappeared by the time region 'E" appears.

"Normal" 3-color images
211Å = red, 193Å=green, 171Å=blue

Persistence map, % change
(quadratically weighted)







Left image: The final Persistence Map is shown in the lower panel, with color outlines corresponding to Regions A - E indicated above. The line plot above the figure compares the values derived from pre-event "base" image subtraction vs. that of the persistence method. The solid black line shows the percentage decrease in integrated emission of the combined areas marked A, B, C, D, and E, normalized to the pre-event value. The dashed black line shows value of emission decrease from the same combined regions as determined by the persistence method.

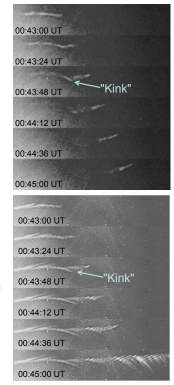
The subtraction vs. persistence values for each of the individual regions A - E are shown using their associated color (A = red, B = blue, etc.). The position of the region's values on the time axis indicates where the integrated emission in the region reached its minimum value. The pie chart superposed on the figure shows the relative contributions of the regions A - E to the total measured dimming.

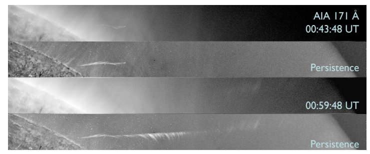
The largest dimming region, C, reaches its minimum value almost two hours after Regions A and B. By this time, the flare loops have already begun to obscure Regions A & B. This can result in a gross underestimate of the total mass loss (45% vs. 65%).

Example problem: Comet Lovejoy

EUV emission from Comet Lovejoy after perihelion. Lovejoy has been studied extensively to understand the source of the EUV emission and its ability to diagnose both the physics of the comet as well as the local solar plasma environment (Bryans & Pesnell, 2012; Downs et al. 2013; McCauley et al. 2013; Schrijver et al. 2013; Raymond et al., 2014).

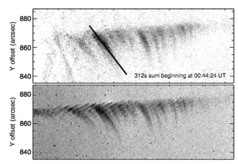
Right image: Solar Dynamics Observatory 171Å images of the comet. The emission displayed distinct changes in morphology throughout the comet's transit throught the solar corona. The morphology traced by the short-lived emission from the comet material, including an apparent "kink" in the comet's tail, can be studied using persistence maps.





Left image: Top: AIA 171Å image from 2011 December 16 at 00:43:48 UT. Second panel: Persistence assembled from AIA images sampled at a 12-second cadence starting at 00:40:11 UT. Third and fourth panels: similar, but later in the comet's egress (16 minutes).

Right image: What appeared to be a "kink" in the comet's emission is revealed in persistence maps to be a bifurcation in the direction of flow. The flow direction switches at least twice during the sequence, indicating a change in local magnetic field topology.

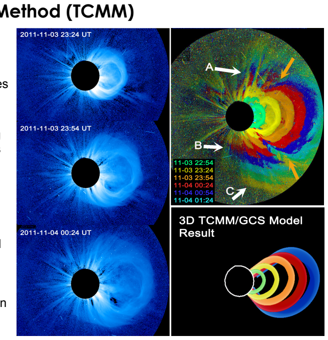


Left image: The top frame shows a sum of 26 consecutive images of Comet Lovejoy from 00:44:24 - 00:49:36 UT (adapted from Raymond et al. (2014)). The black line indicates a reference direction for a single striation. The bottom frame shows the Persistence Map of the same series of images. The increased contrast from the Persistence Map affords an improved identification of the structure of the striations. [All Comet Lovejoy figures from Thompson & Young, 2016]

Time Convolution Mapping Method (TCMM)

One of the well-known obstacles (particularly for fast and wide Coronal Mass Ejections) is separating "true" CME mass from CME-associated brightenings. Our CME identification algorithm, the "Time Convolution Mapping Method," convolves the brightness of the persistence maps with a color scale that indicates the time at which the CME reached the persistence brightness.

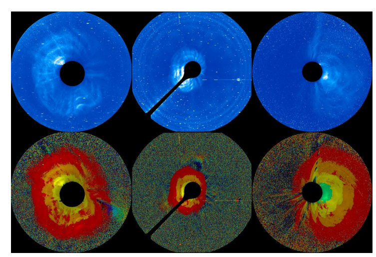
The figure at right shows a CME on November 3, 2011 (STEREO-A COR2). The left three frames show a CME with a clear cavity and a fairly distinct leading edge, but not a clear flank edge. The CDAW catalog LASCO measurement lists a full (360 degree) halo with a speed of 991 km/s, SEEDS gives a width of 70 degrees and a speed of 685 km/s, while CACTUS gives 346 degrees and 589 km/s.



The upper right frame in the figure illustrates the TCMM technique. Eight different image times are represented in the persistence map, six of which show the CME. The time code is shown on the figure. It is the convolution of temporal and spatial information into a single representation that makes this relatively straightforward method so effective. The orange arrows indicate the "true" edge of the CME (which is indeed expanding in width, but not nearly as much as preliminary brightness-based measurements would suggest). The CME can then be extracted using curvelet or other techniques, while the many separate propagating flank structures indicated by white arrows (each distinct "rainbow" profile indicates a different propagation topology in the TCMM map) can each be extracted separately.

This accomplishes two important things: 1) it allows a much more accurate determination of the trajectory and expansion in CME images, affording a significant improvement in the determination of the 3D kinematics of the "true" CME, and 2) it provides a map of how the CME is impacting the surrounding corona, particularly regarding the production of shocks and energetic particles, and produces impact profiles that can also extrapolated to 3D.

The user can use the compression/deflection profiles to: 1) Identify shock structures and shock-associated phenomena 2) map to inner coronal EUV wave structures as well as dimming and flare signatures 3) (when possible) make determinations of shock standoff distance and inferred magnetic field strength.



Right image: Upper panels: Persistence maps of Coronal Mass Ejection on 2013-Mar-5 as observed by STEREO-B COR2 (left), LASCO C3 (middle) and STEREO-A COR2 (right). Lower panels: Time convolution maps of the CME and shock, showing a clear boundary between affected and unaffected corona.

Each pixel receives a color tag corresponding to its maximum value as a function of time. However, the brightness of the color is scaled to represent how strong the maximum value is relative to the median. The boundary between solid, bright red (CME front) and fainter, mixed colors (unaffected corona) is clear and is readily extracted automation methods.

CONCLUSIONS

- Persistence mapping can be an excellent tool to cope with evolving phenomena and evolving backgrounds.
- Easy pre-processing step for more sophisticated algorithms.
- Integration or "time lapse" imaging uses the full sample, so if you have 100 images in the data set and your desired feature/ phenomenon only appears at a given location for a few images, you're mostly averaging background and noise. A persistence map returns only 1% of the data (hopefully the 1% you want!).
- The Time Convolution Mapping Method (TCMM) highlights separate "rainbow profiles" in coronagraph data, allowing users to separate features with different propagation characteristics and separate the "true" CME from CME-associated brightenings.

Note: As with most methods, processing artifacts can be misleading so always view with original images.

Primary reference: Thompson, B. J. & Young, C. A., Astrophysical Journal, In press, 2016.   bit.ly/barbarathompsonpublications